Searches for galaxies at $z \gtrsim 4$ through Lyman–limit imaging

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Abstract. We present preliminary results of a search for galaxies at $z \gtrsim 4$ through Lyman–limit imaging of the fields of known high–redshift radio–galaxies. Objects were selected by means of their broad–band colours, and spectroscopy of candidate objects in one of the fields has been performed through multi–slit spectroscopy at the 4.2m William Herschel Telescope. These spectra show some of the first $z > 4$ galaxies to be identified using the Lyman break technique.

1. Introduction

Encouraged by the early results of Steidel and others (e.g. Steidel & Hamilton, 1993), and of our own pilot programme imaging a 1.5 arcmin^2 region around the radio galaxy 4C 41.17 (Lacy & Rawlings, 1996), we embarked in November 1995 upon a project to apply the technique of Lyman–limit imaging to fields of area $\sim$40 arcmin^2 around high–redshift radio–galaxies using the Prime Focus of the WHT in La Palma.

Our initial aim was to identify galaxies at redshifts similar to those of the central radio–galaxy in each field, searching for U dropouts in the $3 < z < 4$ fields and B dropouts in those at $z > 4$, with spectroscopic follow-up where possible. We imaged four radio–galaxy fields in total, two of the radio galaxies being at $z > 4$. Our imaging observations are summarised in Table 1.

2. Selection of candidate $z \gtrsim 4$ galaxies

We based our initial selection criteria on the assumption that high redshift galaxies are likely to show a relatively flat spectrum at wavelengths longward of Lyα, a pronounced spectral break at Lyα, and little or no flux below the Lyman limit. For simplicity, we use the AB magnitude system.

Initial candidates were selected according to the following criteria: $21.0 < I < 24.5$ (to eliminate the very faintest objects); no detectable flux in B, or $B - I > 3.4$ (with hindsight, a cutoff in $B - R$ would probably have been better); and $0.8 < R - I < 2.3$, to eliminate objects which are obviously merely very red objects. There remains a possible contamination from intrinsically red objects (e.g. M stars) and galaxies at lower redshift, particularly those with a strong 4000Å break.

Colour–colour plots for the magnitude ranges in question are shown in Figure 1. Those for objects for which spectra are available are shown in Figure 2.

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Table 1.   Imaging observations

Field	Redshift	Filter	Date	Seeing (arcsec)	Total integration time (s)	Sensitivity limit[a]
B2 0902+343	3.40	U	20–21.11.95	1.3–2.3	18000	26.3
(Lilly, 1988)		B	21.11.95	≈2.2	1600	25.9
		R	20.11.95	≈1.3	2000	26.0
4C 41.17	3.80	U	22.11.95	≈1.7	18000	26.3
(Chambers *et al.*, 1990)		g	22.11.95	1.9–2.3	2800	26.5
		R	21.11.95	1.4–1.8	2400	26.0
6C 0140+326	4.41	B	21–22.11.95	1.2–1.8	12600	27.2
(Rawlings *et al.*, 1996)		V	20.11.95	≈1.3	1800	25.7
		R	21.11.95	≈1.4	1800	26.1
		I	20.11.95	1.1–1.4	6600	25.7
		Hα[b]	21.11.95	≈1.2	7200	24.1
8C 1435+635	4.25	B	19.04.96	≈1.0	5400	27.0
(Lacy *et al.*, 1994)		R	19.04.96	≈1.1	2700	26.2
		I	19.04.96	0.9–1.1	5400	25.8

[a] 2.5σ limit in AB magnitudes for $1.5''$ radius aperture. In practice galaxies will be detected below these limits if they are sufficiently compact for significant excess flux to be recorded in at least six contiguous pixels.

[b] This narrow-band filter was a redshifted Hα filter with peak response at 656.5nm. This wavelength corresponds approximately to the wavelength of the Lyα line at the redshift of 6C 0140+326.
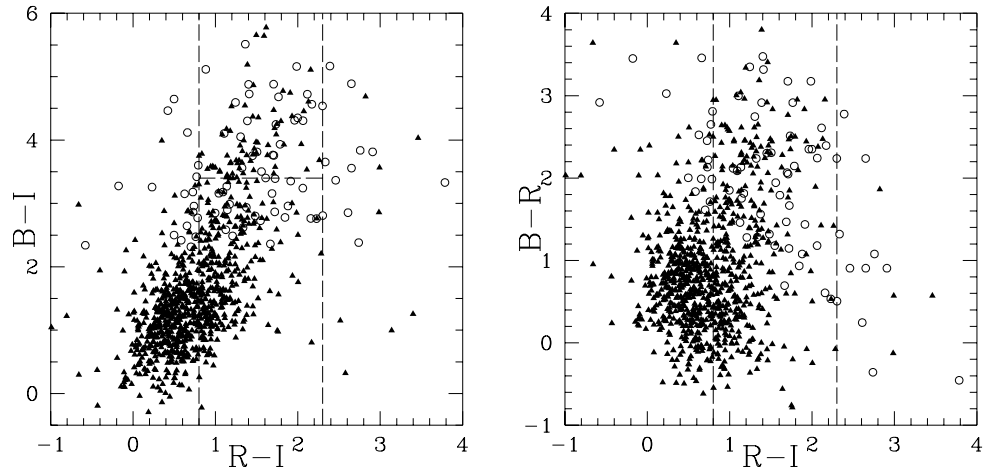

Figure 1.   Colour–colour plots for faint objects $(21.0 < I < 24.5)$ in the field of 6C 0140+326. Triangles are objects which have been detected by FOCAS (Jarvis & Tyson, 1981) in B, R and I; circles show B dropouts. The dashed lines show the limits of our original selection criteria (B dropouts below the $B - I$ limit are also included as candidates). Selection criteria will be reviewed following analysis of real and model spectra, taking into account intergalactic absorption.
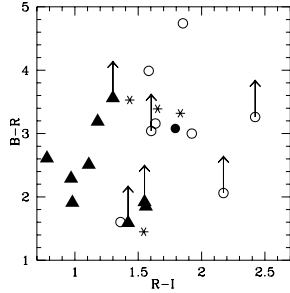
Figure 2. Colour-colour plots of the objects for which we have been able to attempt identification from their spectra. Open circles represent objects which are most likely at $0.3 < z < 0.8$, asterisks are almost certainly stars and the solid circle is possibly a QSO at $z = 1.34$. Triangles are objects for which a high–redshift nature, although not necessarily confirmed, cannot be ruled out.
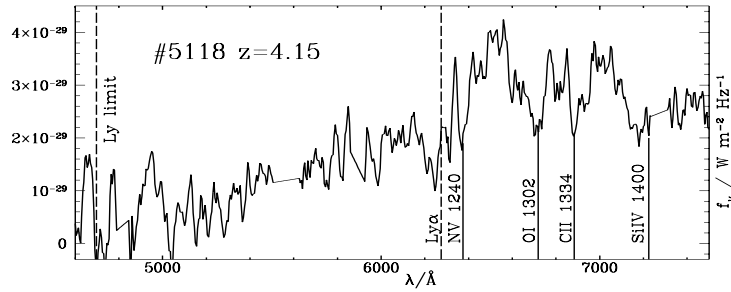

Figure 3. 13645s WHT spectrum of one of our candidates, smoothed with a 25Å boxcar. Some relics of the sky subtraction have been clipped. Although noisy, we believe this spectrum to show a galaxy at a redshift of 4.15, and thus one of the first $z > 4$ galaxies to be found using the Lyman–limit technique.

In the light of the results from our spectroscopic observations and from detailed modelling of the *expected* colours of $z \gtrsim 4$ galaxies, we are looking to see whether our selection criteria can be improved — there is a strong suggestion that we are selecting objects too red in $R - I$ (Figure 2).

3. Spectroscopy in the field of 6C 0140+326

Using the LDSS2 multi-slit spectrometer at the WHT, we took spectra of 49 objects in the 6C 0140+326 field, 42 selected by means of their broadband colours and seven through detection of excess flux through our H_α 656.5nm filter with respect to the broad R. We split the objects across two slit masks according to their R magnitudes, with total integration times 13645s for the brighter objects and 26000s for the fainter ones.

Of these 49, we were unable to determine any significant features on 25 of the spectra, either due to insufficient integration time or through problems with the slit mask such as ghosting or stray light from the alignment stars. Of the remaining 24 for which we were able to deduce anything of the nature of the

object, we find that six are stars, eight are almost certainly galaxies at relatively low redshift ($0.3 < z < 0.8$) and one is most likely a QSO at $z = 1.34$.

Two have spectra with prominent breaks and absorption features consistent with their being $z > 4$ galaxies, one is presented in Figure 3. We believe that these are among the first to be found using the Lyman–limit technique at $z > 4$.

The remaining seven spectra have prominent continuum breaks and/or spectral features not inconsistent with their being at high redshift, although in many cases the possibility that they are low-redshift objects cannot be ruled out.

Table 2.   Possible high–redshift objects as determined from spectra

I.D.	B	V	R	I	6565Å	Possible z
1028	26.44	24.64	23.93	22.82	23.17	0.58 or 4.09
	$K =$22.8, hence $I - K = 0.0 \pm 0.25$ and very flat above continuum break					
122	25.55	25.17	23.70	22.14	24.08	4.02?
	Based on possible identification of 4 absorption features: Nv 1240, Ci 1277, Oi 1302,					
	Cii 1334					
5099	>27.17	24.74	23.61	22.31	>24.1	0.64 or 4.4
	From continuum break only					
5118	25.96	24.19	23.67	22.70	23.40	4.15
	From Nv 1240, Oi 1302, Cii 1334, Siiv 1400					
5123	25.06	24.06	23.15	22.17	22.47	0.58 or 4.1
63	25.98	24.30	23.37	22.59	23.02	3.34??
84	26.86	25.59	23.67	22.49	>24.1	0.6 or 4.3
127	>27.17	>26.1	25.58	24.16	>24.1	0.55 or 4.1
95	>27.17	>26.1	25.25	23.70	>24.1	4.58??
	No continuum detected in spectrum: strong emission at 6785Å (possibly Lyα?)					

4.   Acknowledgements

References

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